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VERIFICATION OF TRANSLATION

I, Michael Wallace Richard Turner, Bachelor of Arts, Chartered Patent Attorney, European Patent Attorney, of 1 Horsefair Mews, Romsey, Hampshire SO51 8JG, England, do hereby declare that I am conversant with the English and German languages and that I am a competent translator thereof;

I verify that the attached English translation is a true and correct translation made by me of the attached specification in the German language of International Application PCT/EP02/12243;

I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment or both under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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Diffractive security element with integrated optical waveguide

The invention relates to a diffractive security element as set forth in the classifying portion of claim 1.

Diffractive security elements of that kind are used for the verification of articles such as banknotes, passes and identity cards of all kinds, valuable documents and so forth in order to be able to establish the authenticity of the article without involving a high level of cost. When the article is issued the diffractive security element is fixedly joined thereto, in the form of a stamp portion cut from a thin layer composite.

Diffractive security elements of the kind set forth in the opening part of this specification are known from EP 0 105 099 A1 and EP 0 375 833 A1. Those security elements include a pattern of surface elements which are arranged in a mosaic-like fashion and which have a diffraction grating. The diffraction gratings are azimuthally predetermined in such a way that, upon a rotary movement, the visible pattern produced by diffracted light performs a predetermined sequence of movements.

US No 4 856 857 describes the structure of transparent security elements with impressed microscopically fine relief structures. Those diffractive security elements generally comprise a portion of a thin layer composite of plastic material. The interface between two of the layers has microscopically fine reliefs of light-diffracting structures. To enhance reflectivity the interface between the two layers is covered with a mostly metallic reflection layer. The structure of the thin layer composite and the materials which can be used for that purpose are described for example in US No 4 856 857 and WO 99/47983. It is known from DE 33 08 831 A1 for the thin layer composite to be applied to an article by means of a carrier film.

The disadvantage of the known diffractive security elements lies in the difficulty of visually recognising complicated, optically varying patterns in a narrow solid angle and the extremely high level of surface brightness, at which a surface element occupied by a diffraction grating is visible to an

observer. The high level of surface brightness can also make it difficult to recognise the shape of the surface element.

A security element which is simple to recognise is known from WO 83/00395. It comprises a diffractive subtractive color filter which, upon illumination with for example daylight, in a viewing direction, reflects red light and, after rotation of the security element in the plane thereof through 90°, reflects light of another color. The security element comprises fine bars, embedded in plastic material, the bars being of a transparent dielectric with a refractive index which is much greater than that of the plastic material. The bars form a grating structure with a spatial frequency of 2500 lines/mm and reflect in the zero diffraction order red light with a very high level of efficiency if the white light incident on the bar structure is polarised in such a way that the E-vector of the incident light is oriented in parallel relationship with the bars. For spatial frequencies of 3100 lines/mm the bar structure reflects green light in the zero diffraction order, while for even higher spatial frequencies the reflected color goes into the blue range in the spectrum. According to van Renesse, Optical Document Security, 2nd Edition, pages 274-277, ISBN 0-89006-982-4, such structures are difficult to produce inexpensively in large amounts.

US No 4 426 130 describes transparent, reflecting sinusoidal phase grating structures. The phase grating structures are so designed that they have the highest possible level of diffraction efficiency in one of the two first diffraction orders.

The object of the present invention is to provide an inexpensive diffractive security element which is simple to recognise and which in daylight can be easily visually checked.

The specified object is attained in accordance with the invention by the features recited in the characterising portion of claim 1. Advantageous configurations of the invention are set forth in the appendant claims.

Embodiments by way of example of the invention are described in greater detail hereinafter and are illustrated in the drawing in which:

Figure 1 is a view in cross-section of a security element,

Figure 2 shows diffraction planes and diffraction gratings,

Figure 3 shows a portion from Figure 1 on an enlarged scale,

Figure 4 shows a view in cross-section of another security element,

Figure 5 shows grating vectors of an optically effective structure,

Figure 6 shows a plan view of a security stamp or tag with the azimuth 0°, and

Figure 7 shows a plan view of the security stamp or tag with the azimuth 90°.

In Figure 1 reference 1 denotes a layer composite, 2 a security element, 3 a substrate, 4 a base layer, 5 an optical waveguide, 6 a protective layer, 7 an adhesive layer, 8 indicia and 9 an optically effective structure at the interface between the base layer 4 and the waveguide 5. The layer composite 1 comprises a plurality of layer portions of various dielectric layers which are applied successively to a carrier film (not shown here) and in the specified sequence includes at least the base layer 4, the waveguide 5, the protective layer 6 and the adhesive layer 7. For particularly thin layer composites 1 the protective layer 6 and the adhesive layer 7 comprise the same material, for example a hot melt adhesive. In an embodiment the carrier film is part of the base layer 4 and forms a stabilisation layer 10 for a shaping layer 11 arranged on the surface of the stabilisation layer 10, which faces towards the waveguide 5. The join between the stabilisation layer 10 and the shaping layer 11 has a very high level of adhesive strength. In another embodiment a separating layer (not shown here) is arranged between the base layer 4 and the carrier film as the carrier film only serves for applying the thin layer composite 1 to the substrate 3 and is thereafter removed from the layer composite 1. The stabilisation layer 10 is for example a scratch-resistant lacquer for protecting the softer shaping layer 11. This configuration of the layer composite 1 is described in above-mentioned DE 33 08 831 A1. The base layer 4, the waveguide 5, the protective layer 6 and the adhesive layer 7 are transparent but preferably crystal-clear at least for a part of the visible spectrum. Therefore the indicia 8 which are possibly covered on the substrate by the layer composite 1 are visible through the layer composite 1.

In another embodiment of the security element in which transparency is not required the protective layer 6 and/or the adhesive layer 7 is colored or black. A further configuration of the security element only has the protective layer 6 if that embodiment is not intended for being stuck on.

The layer composite 1 is produced for example in the form of a plastic laminate in the form of a long film web with a plurality of mutually juxtaposed copies of the security element 2. The security elements 2 are for example cut out of the film web and joined to the substrate 3 by means of the adhesive layer 7. The substrate 3, mostly in the form of a document, a banknote, a bank card, a pass or identity card or another important or valuable article, is provided with the security element 2 in order to verify the authenticity of the article.

So that the waveguide 5 is optically effective the waveguide 5 comprises a transparent dielectric, the refractive index of which is considerably higher than those of the plastic materials for the base layer 4, the protective layer 6 and the adhesive layer 7. Suitable dielectric materials are set out for example in above-mentioned specifications WO 99/47983 and US No 4 856 857, Tables 1 and 6. Preferred dielectrics are ZnS, TiO_2 and so forth with refractive indices of $n \approx 2.3$.

The waveguide 5 fits closely to the interface relative to the shaping layer 11, which has the optically effective structure 9, and is therefore modulated with the optically effective structure 9. The optically effective structure 9 is a diffraction grating with such a high spatial frequency f that the light incident 13 at an angle of incidence α relative to the surface normal 12 of the security element 2 is diffracted by the security element 2 only into the zero diffraction order and the diffracted light 14 is reflected at the angle of reflection β, wherein: angle of incidence α = angle of reflection β. This establishes for the spatial frequency f a lower limit of about 2200 lines/mm and an upper limit for a period length d of 450 nm. Those diffraction gratings are referred to as 'zero order diffraction gratings' and are meant by 'diffraction grating'. In the drawing in Figure 1 by way of

example the diffraction grating is of a sinusoidal profile but other known profiles can also be used.

The waveguide 5 begins to perform its function, that is to say to influence the reflected light 14, if the waveguide 5 includes between at least 10 and 20 periods of the optically effective structure 9 and therefore has a minimum length L, dependent on the period length d, of $L > 10d$. Preferably the lower limit of the length L of the waveguide 5 is in the range of between 50 and 100 period lengths d so that the waveguide 5 affords its optimum effectiveness.

In an embodiment the security element 2, over its entire area, has a uniform diffraction grating for the optically effective structure 9 and a waveguide 5 of uniform layer thickness s. In another embodiment surface portions arranged in a mosaic configuration form an optically easily recognisable pattern. So that a surface portion of the mosaic can be recognised by an observer using the naked eye, in its contours, the dimensions are to be selected to be larger than 0.3 mm, that is to say at any event the waveguide 5 is of a sufficient minimum length L.

The security element 2 which is illuminated with white diffuse incident light 13 changes the color of the reflected diffracted light 14 if its orientation relative to the viewing direction is altered by means of a tilting or rotary movement. The axis of rotation of the rotary movement is the surface normal 12 while the tilting movement takes place about an axis of rotation which is in the plane of the security element 2.

The zero order diffraction gratings exhibit a pronounced behaviour in relation to polarised light 13, which is dependent on the azimuthal orientation of the diffraction grating. For describing the optical properties involved, in Figure 2 diffraction planes 15, 16 are defined parallel and transversely with respect to the grating lines, wherein the diffraction planes 15, 16 additionally include the surface normal 12 on to the security element 2 (Figure 1). The designations of light beams B_p, B_n of the incident light 13 (Figure 1) and directions of polarisation of the incident light 13 are to be established as follows:

- a subscript 'p' designates the light beam B_p which is incident parallel to grating lines while a subscript 'n' designates the light beam B_n which is incident perpendicularly to the grating lines;

- a subscript 'TE' in relation to the light beam B_p, B_n denotes polarisation of the electrical field perpendicularly to the corresponding diffraction plane 15 and 16 respectively and

- a subscript 'TM' refers to polarisation of the electrical field in the corresponding diffraction plane 15 and 16 respectively.

For example the light beam B_{nTM} is incident in the diffraction plane 16 perpendicularly on to the grating lines of the security element 2, with polarisation of the electrical field in the diffraction plane 16.

Depending on the respective parameters of the optically effective structure 9 and the waveguide 5 (Figure 1), the respective embodiments of the security element 2 involve differing optical behaviour. Embodiments of that nature are described in the examples hereinafter which do not constitute a conclusive listing.

Example 1: Change of color upon rotation

Figure 3 shows the waveguide 5 in cross-section on an enlarged scale. The plastic layers, the stabilisation layer 10, the shaping layer 11, the protective layer 6 and the adhesive layer 7 (Figure 1), in accordance with Table 6 of US No 4 856 857, have refractive indices n_1 in the range of between 1.5 and 1.6. The dielectric which is transparent for visible light 13 (Figure 1), with the refractive index n_2, is deposited uniformly in a layer thickness d on the optically effective structure 9 formed in the shaping layer 11, so that on the interface towards the protective layer 6 the surface of the waveguide 5 also has the optically effective structure 9. The dielectric is an inorganic compound as mentioned for example in US No 4 856 857, Table 1 and in WO 99/47983, and is of a value in respect of the refractive index n_2 of at least $n_2 = 2$.

In an embodiment of the security element 2 the values for the profile depth t of the optically effective structure 6 and the layer thickness s are approximately equal: that is to say $s \approx t$, the waveguide 5 being modulated with the period d = 370 nm. Preferably the layer thickness is $s \cong t = 75 \pm 3$

nm. If the light beam B_{nTE} incident in the one diffraction plane 16 (Figure 2) is incident on the security element 2 at an angle of incidence $\alpha = 25°$, the security element 2 reflects the diffracted light 14 (Figure 1) as a green color. Light 14 is reflected from the orthogonally polarised light beam B_{nTM} only in the infrared, invisible part of the spectrum. The light beam B_{pTM} which is incident in the other diffraction plane 15 at the same angle of incidence $\alpha = 25°$ leaves the security element 2 as diffracted light 14 of a red color while the diffracted light 14 produced by the light beam B_{pTE} is of an orange mixed color of a level of intensity which is weak in comparison with the reflected light 14 of the light beam B_{pTM}. The color of the security element 2 changes upon illumination with white, unpolarisedly incident light 13 from the point of view of an observer from green to red upon rotary movement of the security element 2 through 90°. Tilting the security element 2 in the range of $\alpha = 25° \pm 5°$ only immaterially changes the color; the change can scarcely be observed with the naked eye. In the rotary angle range $0° \pm 20°$ only the red B_{pTM} reflection is visible while in the rotary angle range $90° \pm 20°$ only the green B_{nTE} reflection is visible. In the intermediate range between 20° and 70° there is a mixed color comprising two adjacent spectral ranges, one for the component of B_{nTE} and the other for the component of B_{pTM}.

That behaviour on the part of the security element 2 does not change substantially, except for slight color shifts, if the layer thickness of the waveguide 5 is varied between 65 nm and 85 nm and the profile depth t between 60 nm and 90 nm.

A reduction in the period length d to 260 nm in other embodiments shifts the color of the diffracted light 14 with an incident light beam B_{nTE} from green to red and with an incident light beam B_{pTM} from red to green. The color red produced by the light beam B_{nTE} changes to orange upon tilting of the security element 2 in the direction of smaller angles in the region of $\alpha = 20°$.

Example 2: Tilting-invariant color

Another embodiment of the security element 2 exhibits an advantageous optical behaviour as, upon illumination with white

unpolarised light 13, for small tilting angles, corresponding to the angle of incidence between $\alpha = 10°$ and $\alpha = 40°$, the color of the diffracted light 14 remains practically invariant. The parameters of the waveguide 5, the layer thickness s and the profile depth t are here linked by the relationship $s \approx 2t$. For example the layer thickness s = 115 nm and the profile depth t = 65 nm. The period length d of the optically effective structure 9 is d = 345 nm. In the specified range of the tilt angle with illumination with white unpolarised light 13 in parallel relationship with the grating lines of the optically effective structure 9 the diffracted light 14 is of a red color, to which the light beams B_{pTM} primarily contribute. Upon a rotary movement of the security element 2 through a few degrees of azimuth angle the reflected color remains red while upon a further increasing rotary angle two colors are reflected symmetrically with respect to red, of which the shorter-wave color shifts in the direction of ultraviolet and the longer-wave color rapidly disappears in the infrared range. For example with an azimuth angle of 30° the shorter-wave color is an orange; the longer-wave color is invisible to the observer.

Example 3: Color change upon tilting

If the security element 2 is rotated in such a way that the incident light 13 is directed in perpendicular relationship to the grating lines, the security element 2 of Example 2, upon tilting about an axis in parallel relationship with the grating lines of the diffraction grating, exhibits a color shift: for example the observer views the surface of the security element 2 with perpendicular incidence of light, that is to say with an angle of incidence $\alpha = 0°$, as an orange, with an angle of incidence $\alpha = 10°$ the observer sees a mixed color comprising about 67% green and 33% red and with an angle of incidence $\alpha = 30°$ he sees an almost spectrally pure blue.

Example 4: Rotationally invariant color change upon tilting

In another embodiment of the security element 2 the optically effective structure 9 comprises at least two mutually crossing diffraction gratings. The diffraction gratings advantageously cross at intersection angles in the range of between 10° and 30°. Each diffraction grating is determined for example by a profile depth t of 150 nm and a period length

of $d = 417$ nm. The layer thickness s of the waveguide 5 is $s = 60$ nm so that the parameters s and t of the waveguide 5 satisfy the relationship $t \approx 3s$. Upon illumination with white, unpolarised incident light 13 in perpendicular relationship to the grating lines of the first diffraction grating, upon tilting about an axis parallel to the grating lines of the first diffraction grating, there is a color shift, for example from red to green or vice versa. That behaviour is maintained after a rotation through the angle of intersection as now the tilt axis is oriented in parallel relationship with the grating lines of the second diffraction grating.

Example 5: With asymmetrical sawtooth relief profile

In the further embodiment of the security element 2 which is shown in cross-section in Figure 4 the optically effective structure 9 is a superimposition of the zero order diffraction grating with the diffraction grating vector 19 (Figure 5) and with an asymmetrical sawtooth-shaped relief profile 19 with a low spatial frequency of $F \leq 200$ lines/mm. That is advantageous in terms of viewing the security element 2 as, for many people, viewing the above-described security elements 2 at the reflection angle β (Figure 1) is very unfamiliar. The highest permissible spatial frequency F depends on the period length d (Figure 3) of the optically effective structure 9. In accordance with the above-specified criteria for good efficiency, the length L of the waveguide 5 is within a period of the relief profile 17 of at least $L = 10d$ through $20d$, preferably however $L = 50d$ through $100d$. With a largest period length $d = 450$ nm, with $L = 10d$ or $20d$ respectively, the spatial frequency F of the relief profile 17 is accordingly to be selected to be less than $F = 1/L < 220$ lines/mm and 110 lines/mm respectively.

In accordance with the height of the relief profile 17 or a blaze angle γ of the sawtooth profile, upon illumination of the security element 2 by means of light 13 which is incident at the angle of incidence α measured with respect to the surface normal 12, the diffracted light 14 is reflected at a larger reflection angle β_1. The incident light 13 is incident at the angle $\gamma + \alpha$ relative to the perpendicular 18 on to the plane of the waveguide 5, which is inclined by virtue of the relief profile 17, and is reflected in the

form of diffracted light 14 at the same angle relative to the perpendicular 18. The reflection angle β_1, related to the surface normal 12, is $\beta_1 = 2\gamma + \alpha$. The advantage of that arrangement is facilitated viewing of the optical effect produced by the security element 2. It is to be noted here that refraction in the materials of the layer composite 1 (Figure 1) is disregarded in the drawing of Figure 1. Having regard to the refraction effects in the layer composite 1 period lengths d to about d = 500 nm can be used for the security element as, with that period length, even the blue components of the light 14 diffracted into the first orders, because of total reflection, cannot leave the layer composite 1 (Figure 1). The blaze angle γ is of a value from the range of between $\gamma = 1°$ and $\gamma = 15°$.

Figure 5 shows the optically effective structure 9 which is a superimposition of the diffraction grating with an asymmetrical sawtooth-shaped relief profile 17. The azimuthal orientation of the diffraction grating is established by means of the diffraction grating vector 19 thereof. The relief structure 17 involves the azimuthal orientation specified by the relief vector 20. The optically effective structure 9 is defined by a further parameter, an azimuth difference angle ψ included by the diffraction grating vector 19 and the relief vector 20. Preferred values for the azimuth difference angle are $\psi = 0°$, 45°, 90° and so forth.

In quite general terms a high level of diffraction efficiency of almost 100% is typical of those security elements 2 (Figure 3), at least for one polarisation. The most important parameter of the security element 2 for the color shift capability is the period length d (Figure 3). The layer thickness s (Figure 3) of the waveguide and the profile depth t (Figure 3) are not so critical for the dielectrics ZnS and TiO_2 and only slightly influence the diffraction efficiency and the exact position of the color in the visible spectrum, but they influence the spectral purity of the reflected diffracted light 14 (Figure 4).

The parameters in accordance with Table 1 can be used for those security elements 2.

The parameter period length d determines the color of the light 14 which is diffracted reflected into the zero order. A change in the parameter

layer thickness s of the waveguide 5 (Figure 4) primarily influences the spectral purity of the color of the diffracted light 14 and shifts the position of the color in the spectrum to a slight extent. The profile depth t influences the modulation of the waveguide 5 and therewith the efficiency thereof. Deviations of ± 5% from the values specified in the Examples for d, s, t and ψ do not noticeably influence the described optical effect, for the naked eye. That great tolerance considerably facilitates manufacture of the security element 2.

Table 1:

Parameter (in nanometers)	Limit value range		Preferred range	
	Minimum	Maximum	Minimum	Maximum
Period length d	100	500	200	450
Profile depth t	20	1000	50	500
Layer thickness s	5	500	10	100

Figures 6 and 7 show an embodiment of the security element 2 (Figure 3), on the surface of which is arranged a combination of a plurality of surface portions 21, 22. The surface portions 21, 22 include waveguides 5 (Figure 3) and differ in respect of the optically effective structure 9 (Figure 3) and the azimuthal orientation of the diffraction grating vector 19 (Figure 5). Differences in the layer thickness s of the waveguides 5 in the layer composite 1 (Figure 1) are technically difficult to implement; however they are expressly not excluded here. A stamp portion or tag 23 is cut out of the layer composite 1 and stuck on to the substrate 3. In the illustrated embodiment the stamp portion or tag 23 has two surface portions 21, 22. For illustration purposes, the security element 2 of the above-described Example 1 is used here in Figure 6, the orientation of the diffraction grating vector 19 (Figure 5) of the first surface portion 21 being orthogonal with respect to the diffraction grating vector 19 of the second surface portion 22. The observation direction is in a plane which contains the surface normal 12 and the trace of which is specified in the plane of the drawing in Figures 6 and 7 by the broken line 24. For the first surface portion 21, the white unpolarised incident light 13 (Figure 1) is incident in perpendicular relationship to the grating lines while in the case of the second surface portion 22 the incident light 13 is incident in parallel relationship with the

grating lines, at the angle of incidence $\alpha = 25°$. Therefore the observer sees the first surface portion 21 as a green color and the second surface portion 22 as a red color. As the layer composite 1 (Figure 1) is transparent it is possible to recognise indicia 8 of the substrate under the stamp portion or tag 23.

After rotation of the substrate 3 with the stamp portion or tag 23 through an angle of 90°, as shown in Figure 7, the incident light 13 (Figure 1) is incident on the first surface portion 21 perpendicularly to the grating lines of the diffraction grating and on the second surface portion 22 parallel to the grating lines, as is indicated by the angle between hatchings of the surface portions 21, 22 and the line 24 in the drawing in Figure 7. Rotation of the substrate 3 through 90° causes interchange of the colors of the surface portions 21, 22; that is to say the first surface portion 21 shines red and the second surface portion 22 shines green.

In another embodiment of the security element 2 the arrangement of a plurality of identical surface portions 21 on the stamp portion or tag 23 can form a circular ring, the diffraction grating vectors 19 being directed on to the center of the circular ring. With a viewing direction along a diameter of the circular ring, irrespective of the azimuthal position of the substrate 3, the most remote ($0° \pm 20°$) and the closest ($180° \pm 20°$) portions of the circular ring light up in a green color and the regions which are furthest away from the diameter at $90° \pm 20°$ and $270° \pm 20°$ respectively of the circular ring light up in a red color. Regions disposed therebetween exhibit the above-described mixed color comprising two adjacent spectral ranges. The color pattern is invariant with respect to a rotation of the substrate 3 and appears to move relative to any indicia 8 (Figure 1). A circular ring with curved grating lines produces the same effect if the grating lines are arranged concentrically with respect to the center point of the circular ring.

In a further configuration of Figure 7 for example the surface portions 21, 22 are arranged on a background 25. The surface portions 21 and 22 include the optically effective structure 9 (Figure 4) from Example 5, wherein the relief vector 20 (Figure 5) of the one surface portion 21 is in opposite relationship to the relief vector 20 of the other surface portion 22.

The optically effective structure 9 of the background 25 only consists of the diffraction grating which is not modulated by the relief structure 17 (Figure 5). The diffraction grating vector 19 can be oriented parallel or perpendicularly to the relief vectors 20; the angle γ (Figure 5) can certainly also be of other values.

It will be appreciated that, without limitation, all the above-described embodiments of the security elements 2 can advantageously be combined as the specific optical effects which are dependent on the azimuth or the tilt angle, by virtue of the mutual referencing thereof, are substantially more striking and can therefore be more easily recognised.

Finally other embodiments of the security element 2 also have field portions 26 (Figure 6) with grating structures with spatial frequencies in the range of between 300 lines/mm and 1800 lines/mm and azimuth angles in the range of between 0° and 360°, which are used in the surface patterns described in above-mentioned EP 0 105 099 A1 and EP 0 375 833 A1. The field portions 26 extend over the security element 2 and over the surface portions 21, 22, 25 respectively and form one of the known optically variable patterns which changes in a predetermined manner upon rotation or tilting movement independently of the optical effects of the waveguide structures, under identical observation conditions. The advantage of that combination is that the surface patterns enhance the level of security against forgery of the security element 2.